# *UWB Hardware Issues, Trends, Challenges, and Successes*


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# *UWB Motivation*

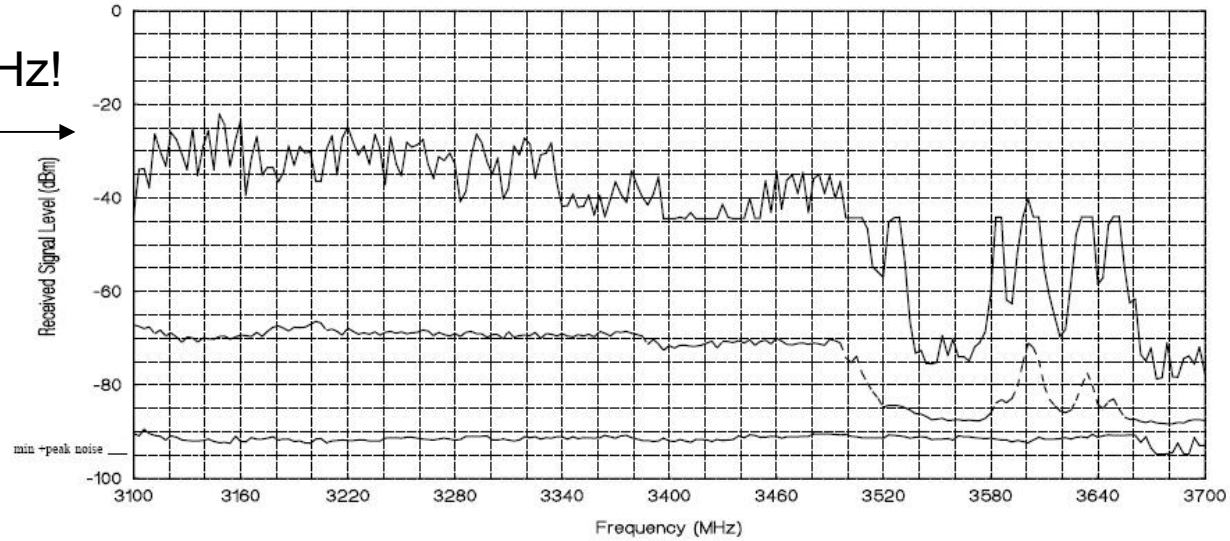
- ***Ultra-Wideband***
  - **Large bandwidth (3.1GHz-10.6GHz)**
  - **Power spectrum density limited: -41.25 dBm/MHz**
  - **Many narrow-band interferers**
    - **5GHz UNII band (802.11a, cordless telephones)**
    - **Airport and Marine Radars**
    - **WiMAX**
  - **Signal generation: Impulse (Gaussian Monopulse), DSSS, OFDM, Spectral Encoding, etc.**

# *Long Run Threat to Wide Adoption of UWB is Interference*

| | | | | |
|---|---|---|---|---|
| GOVERNMENT ALLOCATIONS: | RADIOLOCATION. | RADIOLOCATION. | RADIOLOCATION, 1. | RADIOLOCATION, 1. |
| NON-GOVERNMENT ALLOCATIONS: | Radiolocation. | Amateur, Radiolocation. | Radiolocation. | FIXED-SATELLITE (space-to-Earth), 2. |
| GENERAL UTILIZATION: | 3. | 3. | 3. | INMARSAT, INTELSAT. |

3100 3300 3500 3600 3700

Roughly
-40 dBm/MHz!




1. AERONAUTICAL RADIONAVIGATION (Ground-based).
2. Radiolocation.
3. Primarily, military airborne, land-based, and shipborne defense radars.

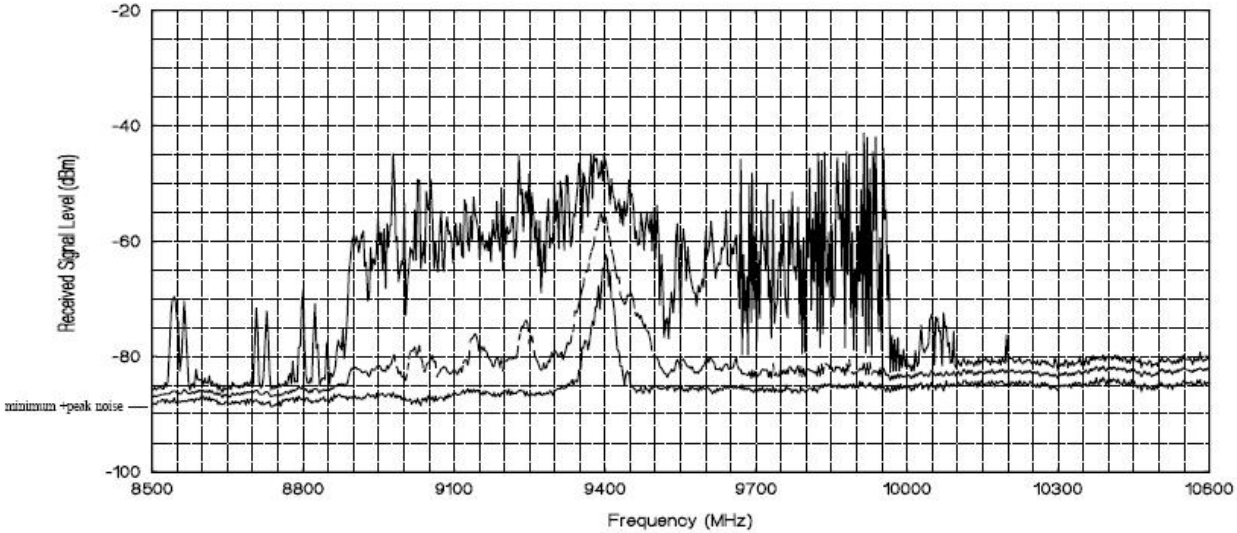
Figure 30. NTIA spectrum survey graph summarizing 70 scans across the 3100-3700 MHz range (System-2, band event 15, stepped algorithm, +peak detector, 3000-kHz bandwidth) at Los Angeles, CA, 1995.

***Radars, Comm. Systems, Military, etc., etc. ……***

# *Long Run Threat to Wide Adoption of UWB is Interference*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| GOVERNMENT ALLOCATIONS: | RADIOLOCATION. | 1. | 2. | 3. | RADIOLOCATION. | | | |
| NON-GOVERNMENT ALLOCATIONS: | Radiolocation. | 1. | 2. | 3. | Radiolocation. | Amateur, Radiolocation. | 6. | |
| GENERAL UTILIZATION: | Military use is primary. | | | 4. | 5. | | | |

8500 9000 9200 9300 9500 10000 10450 10550




1. AERONAUTICAL RADIONAVIGATION, Radiolocation.
2. MARITIME RADIONAVIGATION, Radiolocation.
3. RADIONAVIGATION, Meteorological Aids, Radiolocation.
4. Maritime radionavigation radar, airborne weather radar, radar transponder beacons (RACONS).
5. Military airborne radar.
6. RADIOLOCATION. 10450-10500 MHz: Amateur, Amateur-Satellite.

Figure 38. NTIA spectrum survey graph summarizing 35 scans across the 8500-10550 MHz range (System-2, band event 23, stepped algorithm, +peak detector, 3000-kHz bandwidth) at Los Angeles, CA, 1995.

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# UWB Time Hopping Signals

- ***UWB TH Signal defined as:***

$$s(t) = \sum_n a(n)\, p(t - nT - t_{pn}(n) - t_d d(n))$$

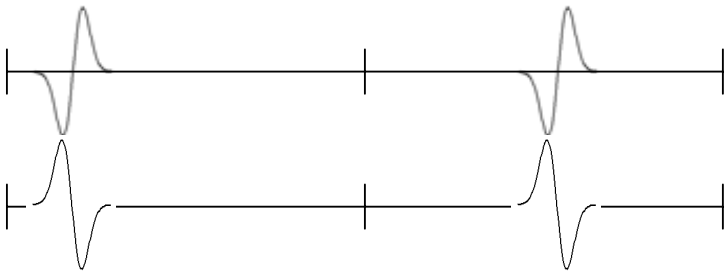
$T$ - frame length

$t_d$ - time offset

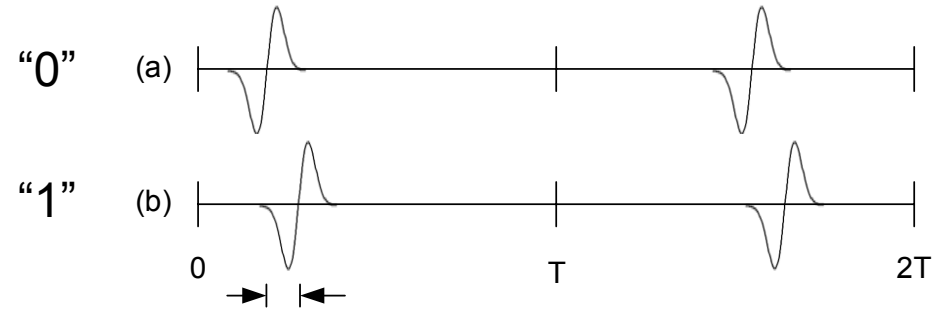
$t_{pn}$ - pseudo-random time offset

$p(t)$ - pulse

$a(n), d(n)$ - data bits

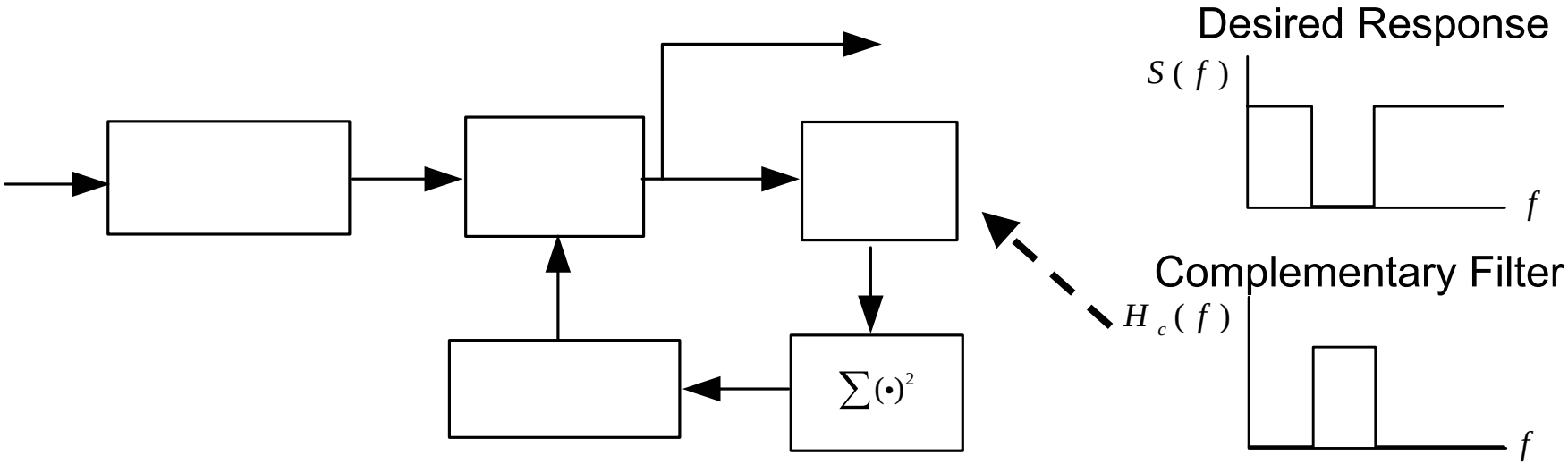


**UWB TH-BPSK**




**UWB TH-PPM**

# *Look Ahead Block Inversion*

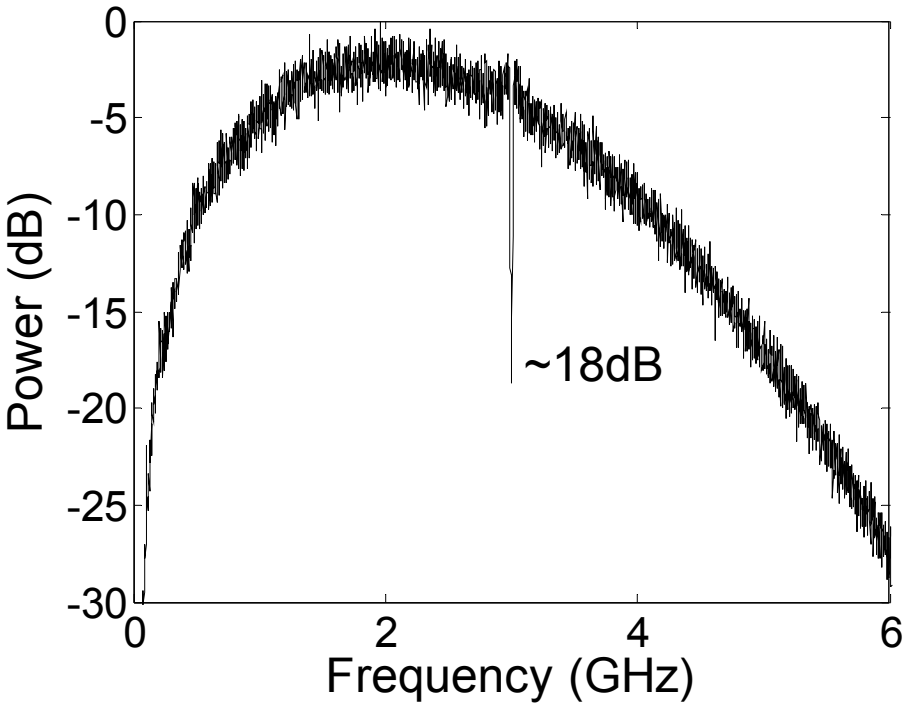



***<u>Goal</u>: Determine the set of flag bit polarities that minimizes the power out of the complementary filter***

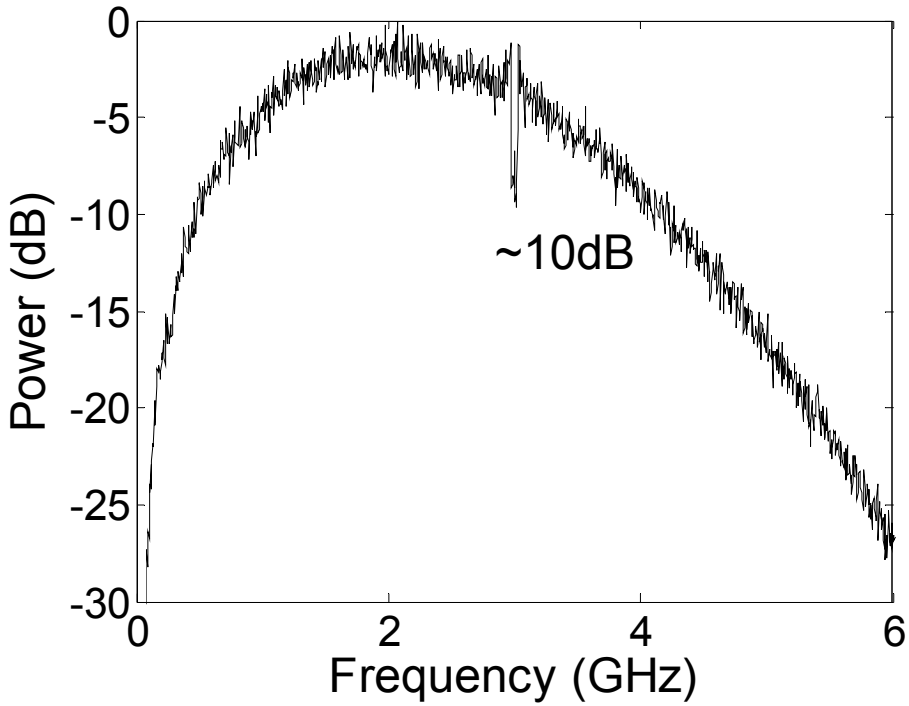
**Minimizes power transmitted in the notch**

$$J(r) = \sum_{i=-\infty}^{r} RIS(i)$$

# *Example of LABI PI Spectral Shaping*



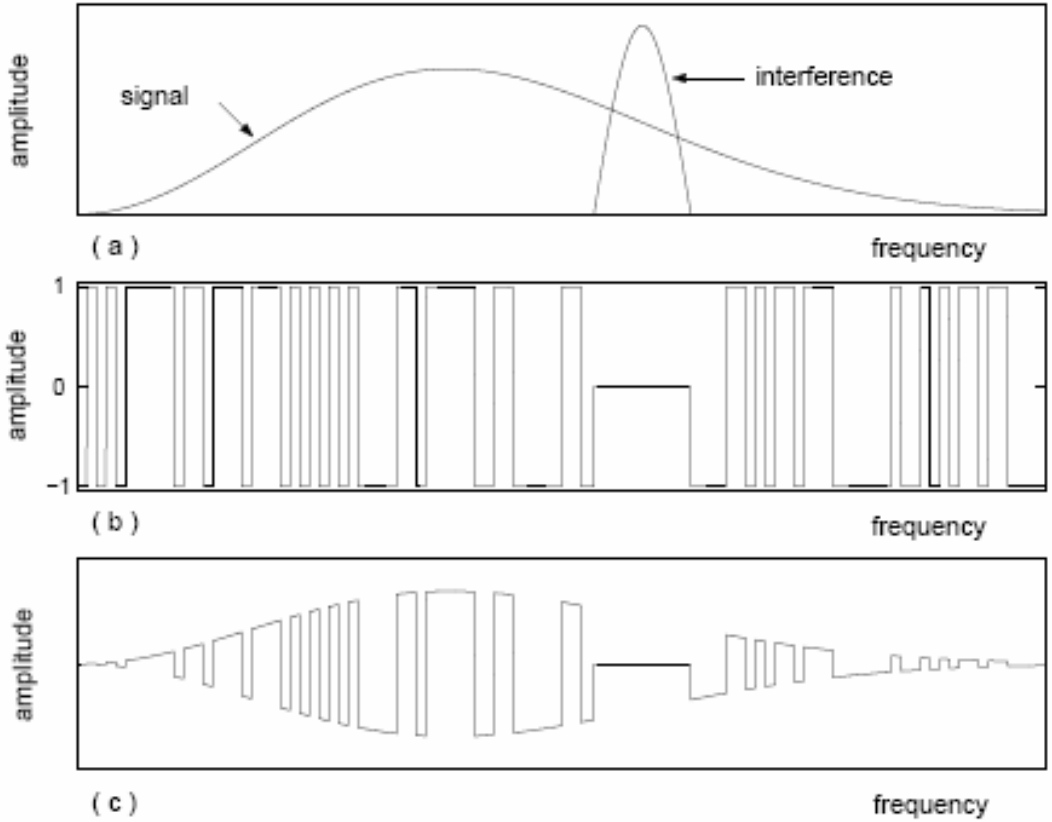

10MHz notch at 3GHz




50MHz notch at 3GHz

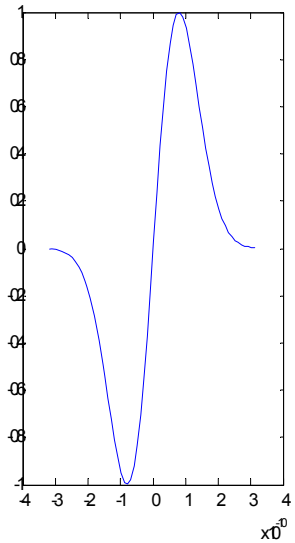
***Smaller blocks lengths and longer filters improve performance***

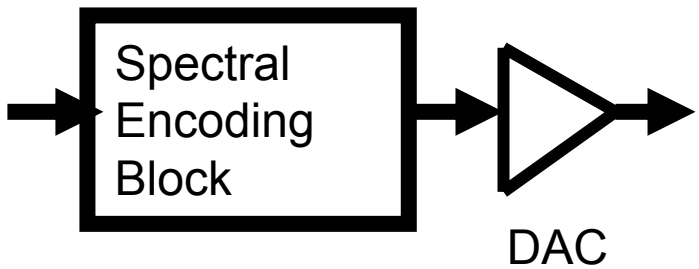
# *UWB Spectral Encoding*

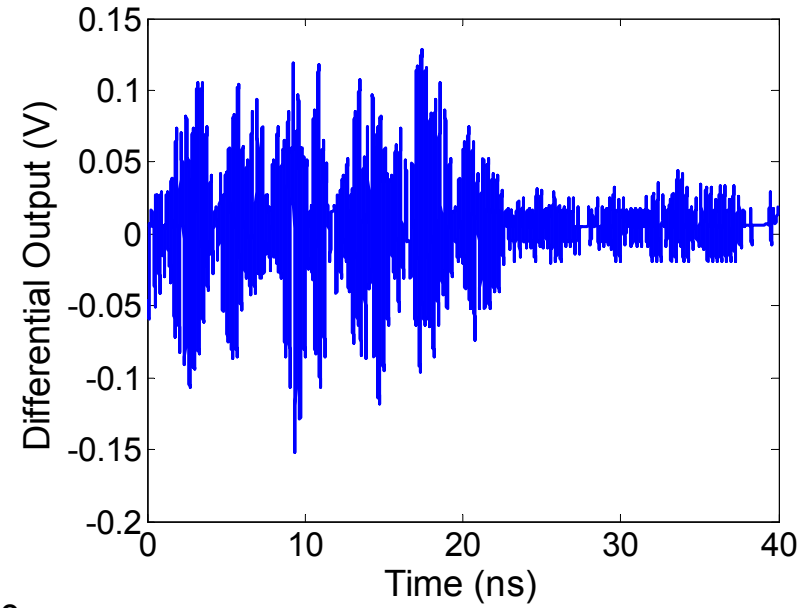


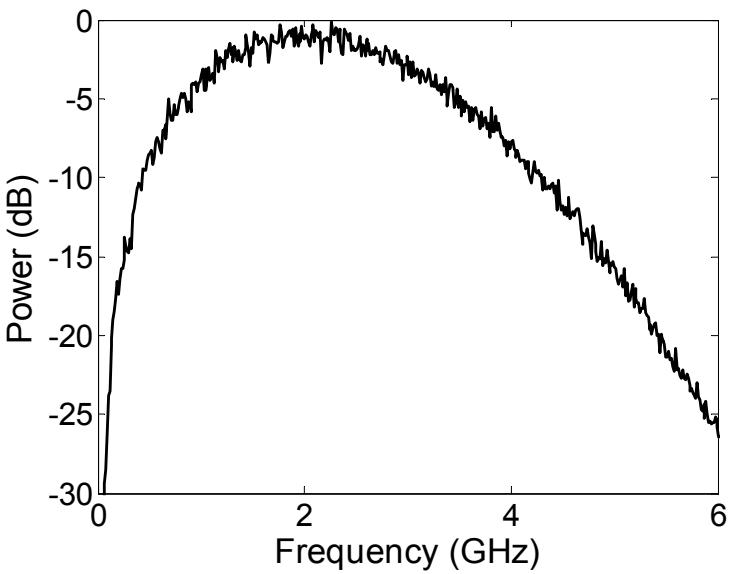

- ***Source: C. da Silva, L. Milstein. "Spectral-Encoded UWB Communication Systems: Real-Time Implementation and Interference Suppression," Trans. Comm., vol. 53, pp. 1391-1401, Aug. 2005.***

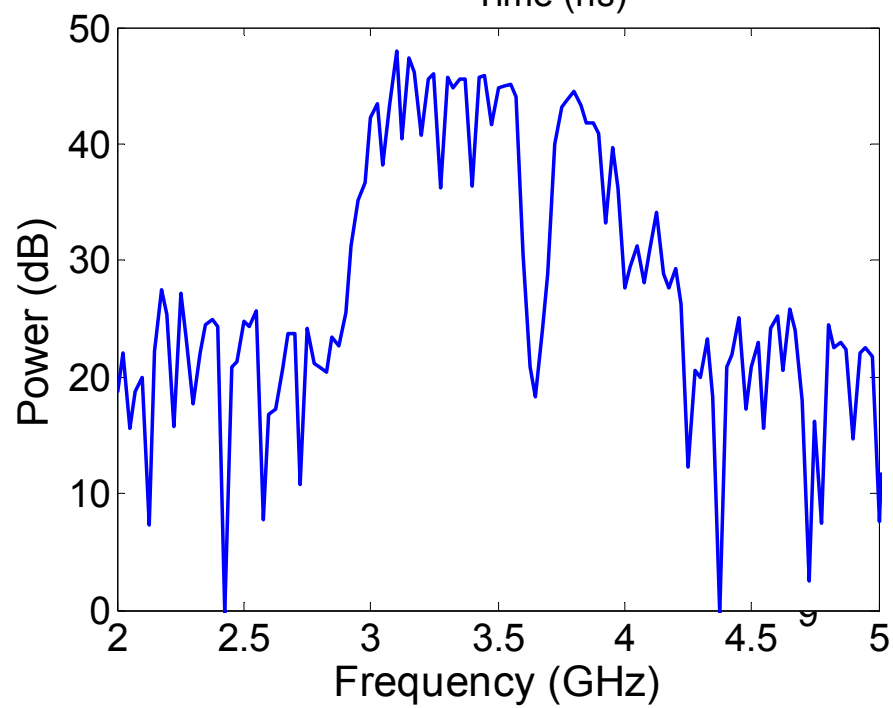
# DAC: Spectral Encoded Waveform



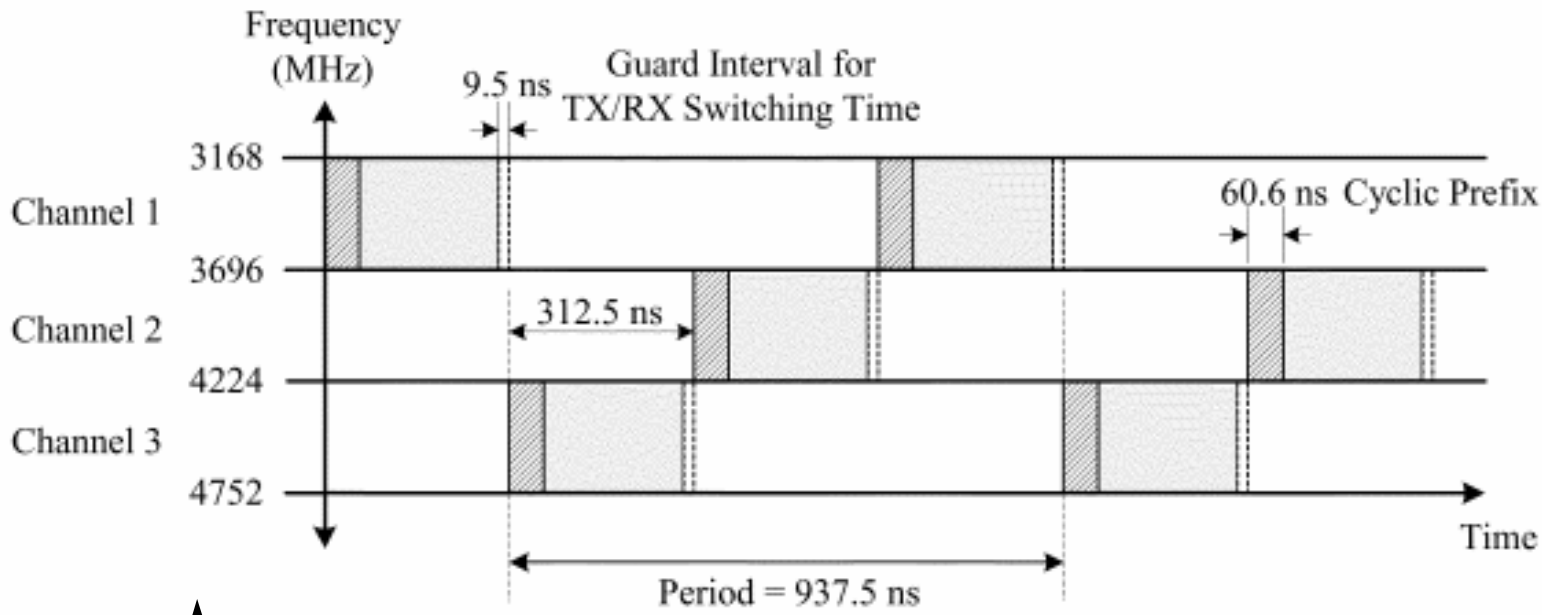


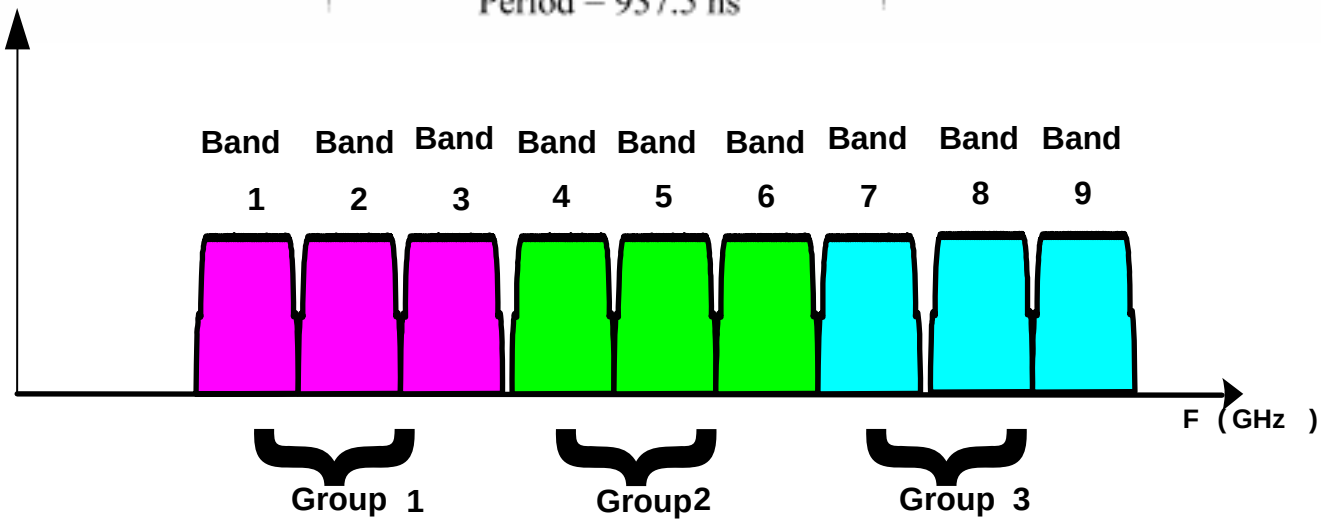



# Multi-Band OFDM Ultra-Wideband Systems - II



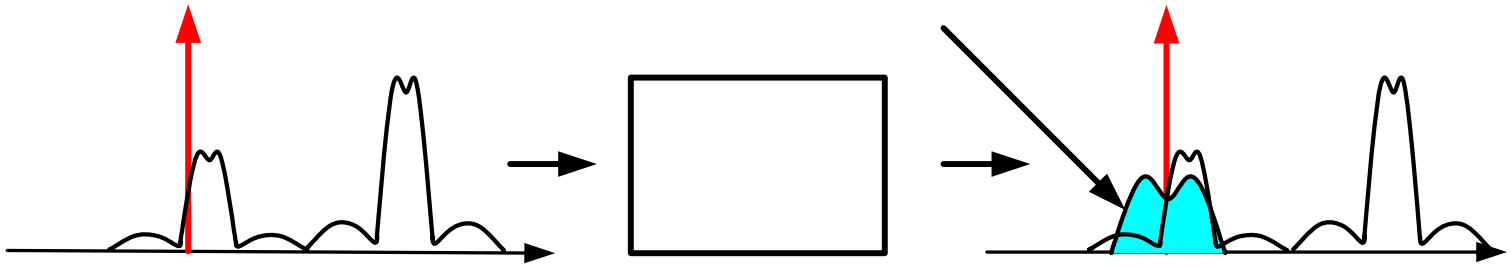



# *Narrow Band Jammers*

**Receivers have a non-linear transfer function**

$$y(t) = c_1 x(t) + c_2 x(t)^2 + c_3 x(t)^3$$

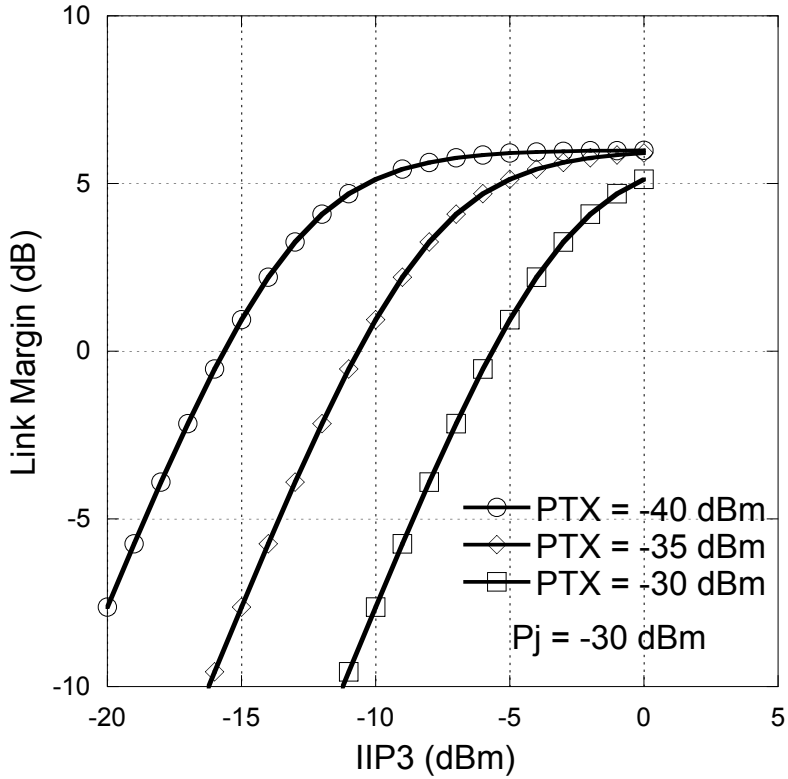
**A wideband spur at the input to the receiver spreads a narrow band jammer to twice its bandwidth due to the 3rd order nonlinearity, reducing the SNR**



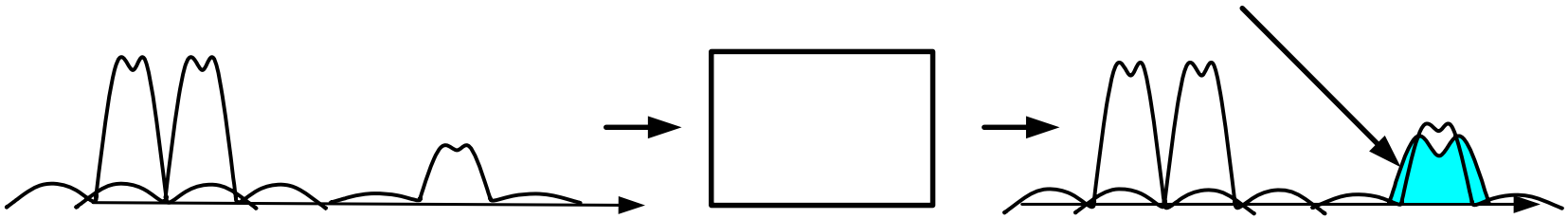
***Need to quantify this cross-modulation product to correctly specify the receiver***

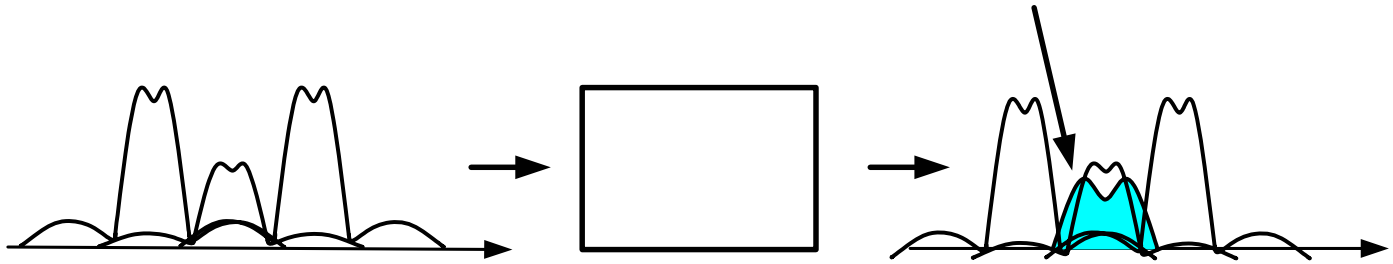
# *Effect of Cross-Modulation on Received SNR*

- ***Calculate noise at the output of receiver from just the LNA and mixer***
- ***Add in-band noise power to this noise to calculate new SNR***



# *Wideband Distortion*





**Sign**

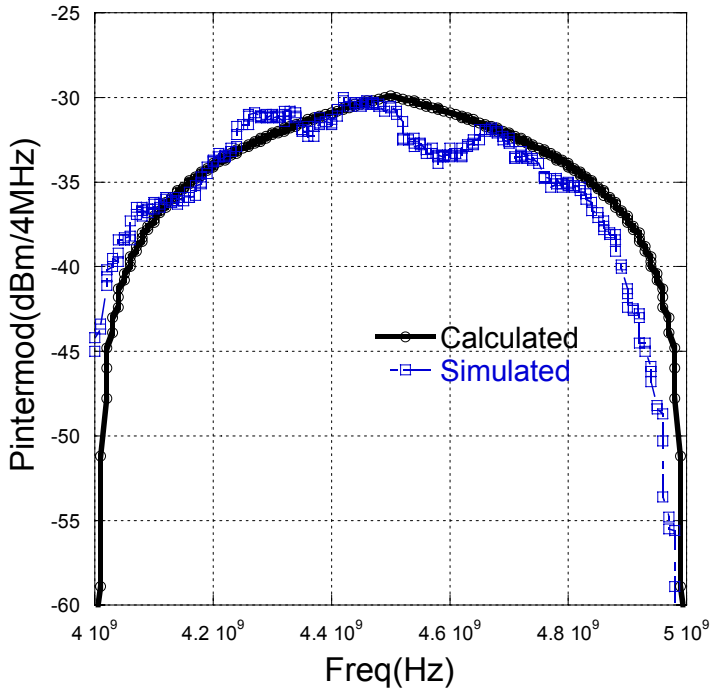
SNR at receiver output drops in the presence of 2 or more signals

*Need to quantify this SNR reduction to accurately specify receiver*

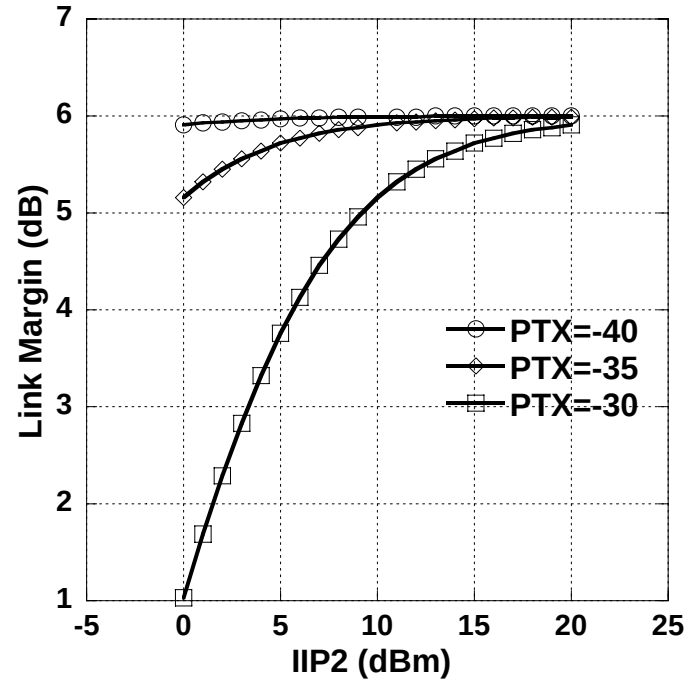
# $2^{nd}$ Order Intermodulation PSD

It can be shown that the PSD of the $2^{nd}$ order intermodulation product is given by

$$PSD(\omega) = c_2^2 A_{tx1}^2 A_{tx2}^2 \frac{T_{sym}}{4} \sum_{\frac{-Ns}{2}}^{\frac{Ns}{2}} \sum_{\frac{-Ns}{2}}^{\frac{Ns}{2}} \sin c((\omega + \omega_1 + \omega_2 + \Delta\omega(m+n))\frac{T_{sym}}{4}) + \sin c((\omega - \omega_1 - \omega_2 - \Delta\omega(m+n))\frac{T_{sym}}{4})$$




Comparison of simulated and calculated $2^{nd}$ order inter-modulation power spectral density




Link budget degradation in the presence of distortion

# *Issues With Standard Receiver Designs*

- ***Suited for narrow band signals***
- ***Consume a lot of die area***
- ***Susceptible to interference***

➢ *Industry focus*

  ➢ **Time to market critical, no time to innovate or take risks**

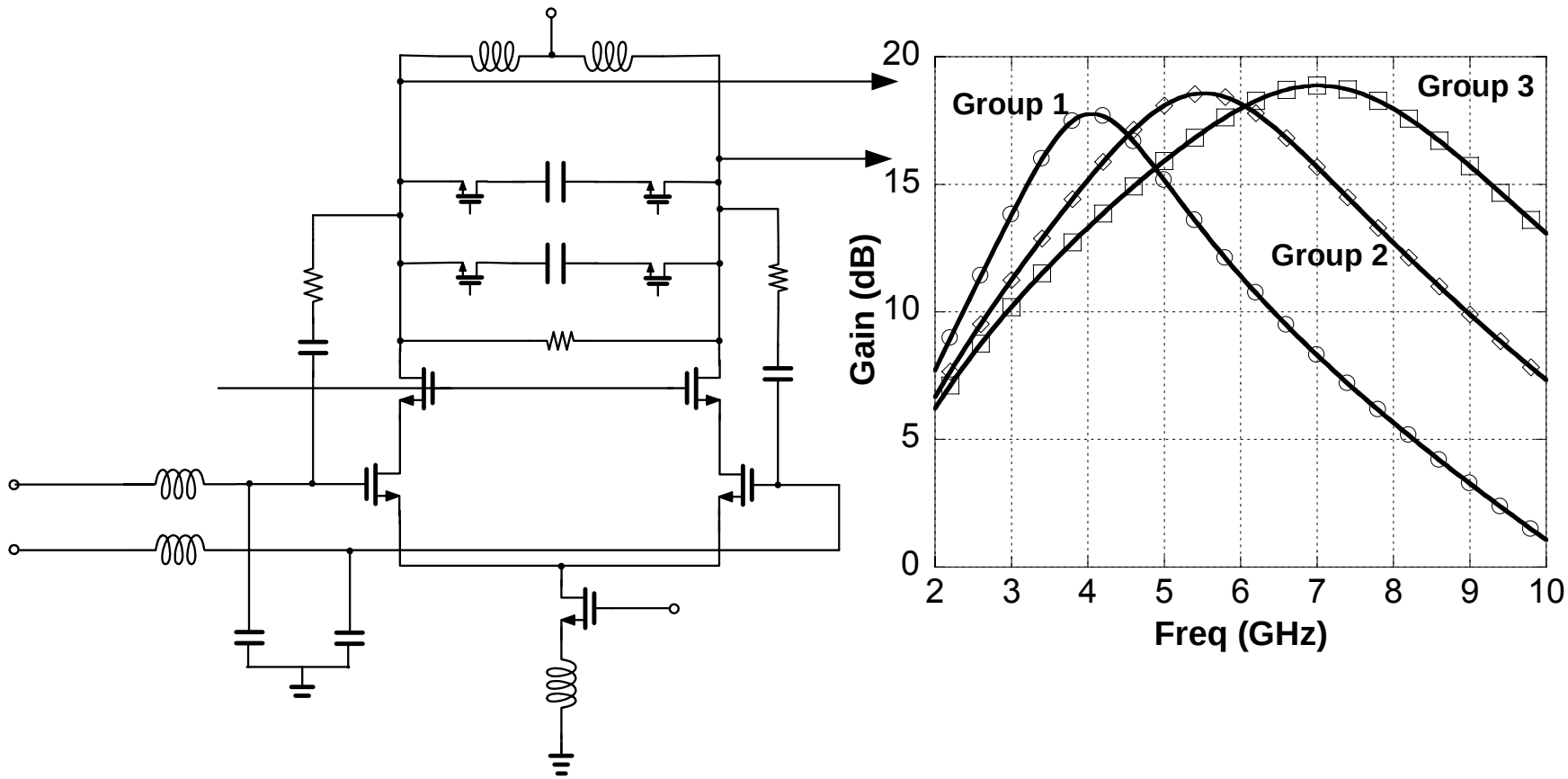
  ➢ **Use a standard design approach and run with it**

➢ *Academia*

  ➢ **Take one step back and re-visit current design techniques. *Are they suitable for a radically new system like MB-OFDM UWB?***

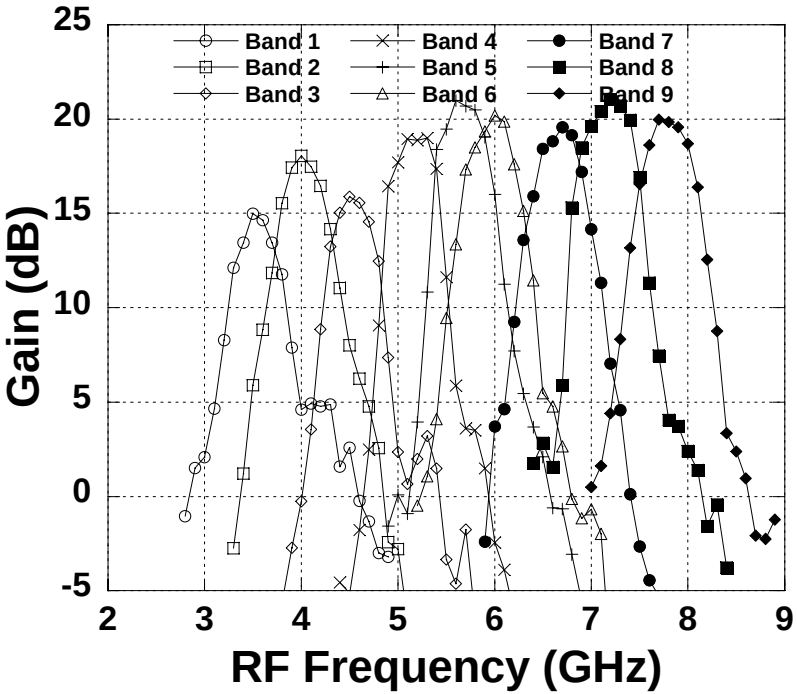
  ➢ **Answer above question with a new innovative solution**

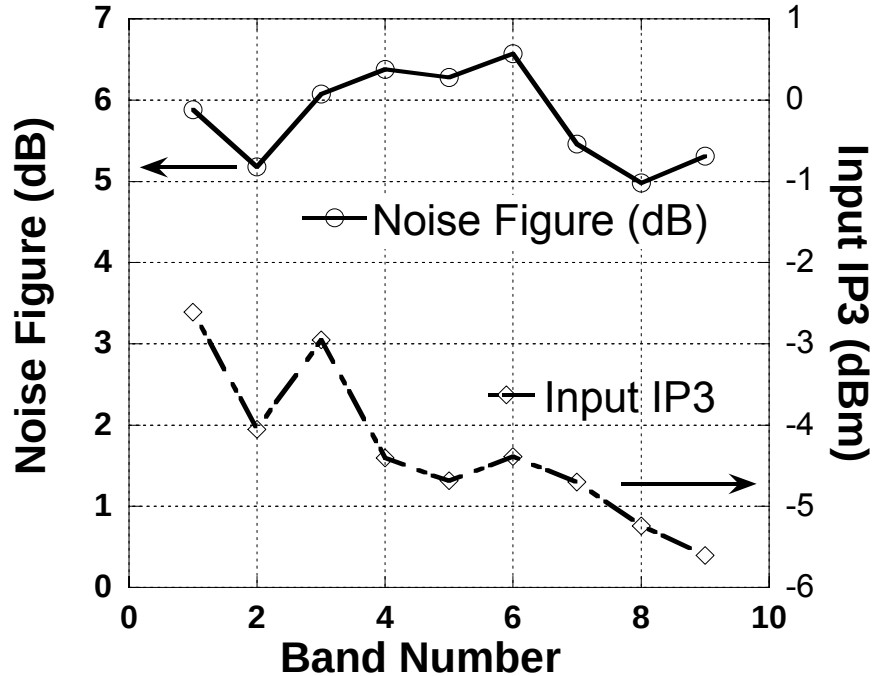
# *Tunable LNA - I*




- **Take advantage of frequency hop nature of MB-OFDM signal**
- **Dynamically tune LNA to desired frequency: “Pseudo UWB LNA”**

# Measurement Results - I




Receiver Gain: 3- 8 GHz

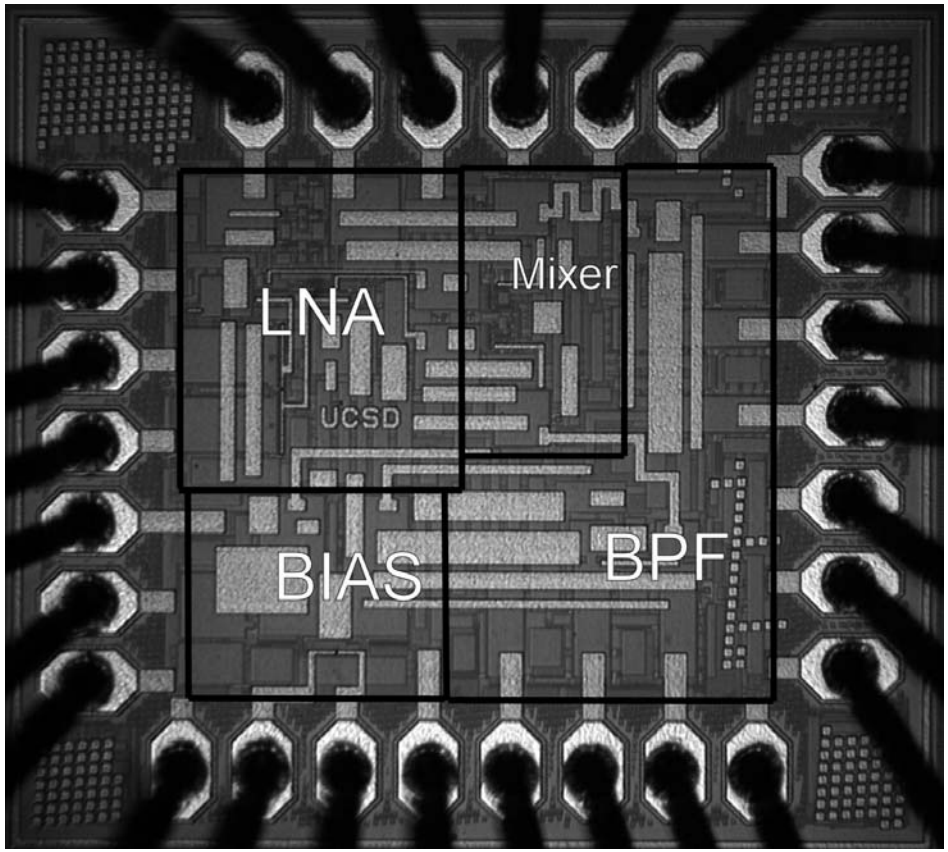
Gain variation over bands ≈ 6 dB

- Not very significant since received power will vary more than this over bands

Noise Figure: 5 to 6.5 dB

Input IIP3: -2.5 to -6 dBm

# *UWB Receiver Die Micrograph*




- 0.18 μM CMOS
- 0.35 $mm^2$
- 19.5 mA Current Consumption
- 2.64 GHz IF
- NO on-chip inductors

# *Conclusions*

- ***UWB Systems will be widely adopted if***
  - **they are very low cost (highly integrated with small die area) and consume little dc power**
  - **are robust against interference across the entire UWB band**